Geomagnetic Disturbances

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LONG-TERM GOALS

The changing magnetic field of the Sun interacts with the Earth's magnetosphere to cause geomagnetic activity. Our goal is to understand the processes that determine the inputs to the terrestrial system and generate magnetospheric disturbances.

How does solar activity originate? How is it expressed in the corona and interplanetary medium? Can we forecast the quantities that determine how the terrestrial environment ultimately responds?

Our aim is to understand the solar causes of geomagnetic disturbances and to build tools that can, from photospheric observations, forecast the conditions that result in space weather disturbances.

OBJECTIVES

To reach our goal, we must observe the Sun and access the data in a timely way, develop our understanding of solar transient processes (e.g., solar flares and coronal mass ejections (CMEs)) and the relationship of these processes to both large and small scale magnetic fields, investigate the linkage of the transients with the interplanetary shocks and southward interplanetary magnetic field (IMF) events and geomagnetic disturbances, and locate the source of fast and slow solar wind streams above the solar surface. To these ends, we pursue four objectives detailed in below.

1. Measurement of the large-scale photospheric magnetic fields that demonstrates distribution, configuration and evolution of magnetic field after the maximum of Solar Cycle 23.

2. Investigation of the relationship of solar magnetic fields and solar transients to clarify the configuration and changes of magnetic fields in both large and small scale, and to reveal ways the magnetic field links with the transients.

3. Improvement and evaluation of models of the solar corona and the solar wind throughout the heliosphere to identify disturbances with solar origins.

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14. ABSTRACT
The changing magnetic field of the Sun interacts with the Earth???s magnetosphere to cause geomagnetic activity. Our goal is to understand the processes that determine the inputs to the terrestrial system and generate magnetospheric disturbances. How does solar activity originate? How is it expressed in the corona and interplanetary medium? Can we forecast the quantities that determine how the terrestrial environment ultimately responds? Our aim is to understand the solar causes of geomagnetic disturbances and to build tools that can, from photospheric observations, forecast the conditions that result in space weather disturbances.

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4. Exploration of the causes of solar transients and their possible link with the southward IMF events to help build tools for space weather forecast.

APPROACH

These objectives require that solar magnetic field measurements be made in a routine manner. The 28 year time series of uniform solar magnetic field measurements taken at the Wilcox Solar Observatory (WSO) at Stanford University is highly valuable for this investigation.

Both preliminary and archival WSO data are made rapidly and conveniently available to other researchers via WSO's website, often by the end of observing day. To facilitate predictions, a variety of data products are also made conveniently available via the web site at http://sun.stanford.edu/~wso and by e-mail and anonymous ftp.

We analyze these magnetic field data, in combination with the data acquired by other instruments such as SOHO, Yohkoh, Ulysses in space and telescopes by National Solar Observatory (NSO), in High Altitude Observatory (HAO) on the ground, to carry out various tasks to pursue our objectives.

X.P. Zhao is mainly responsible for this project, together with two research associates, Drs. B. Balachandran and Y. Liu, under direction of P.H. Scherrer. Routine observation is taken by a graduate student.

WORK COMPLETED

We have been measuring solar magnetic field after the sunspot maximum of solar cycle 23. In the period between 01 October 2002 and 26 September 2003, we obtained 330 magnetograms, and magnetic mean field was measured in 302 days.

Other works are shown in publications and will be summarized below.

RESULTS

Solar active regions have been observed to be associated with solar transients, such as solar flares and coronal mass ejections (CMEs). This relationship is somehow determined by the characteristic of the active regions, which is either described by well-established laws such as Hale law or represented by morphological patterns such as delta-structures. Most of these are defined by magnetic field structure. We thus performed a series of investigations to study the magnetic configuration of active regions and to exploit intrinsic relations to solar activity (Tian, Liu, and Wang, 2002; Tian, Liu, and Wang, 2003, Tian and Liu, 2003a, b). From these studies, we learned that the signs of magnetic twist and writhe are the same for flare-producing active regions but different from active regions having well-defined bipolar magnetic configurations, which implies that a kink instability has developed in the flare-producing active regions. We also found that the flare-producing active regions have significant net magnetic flux, and present abnormal magnetic configurations such as violating the Hale-Nicholson Law, large tilt angle, and strong magnetic twist and writhe, and these active regions tended to occur preferentially in the certain longitudes. For a sample of 12 active regions with strong solar storms, we measured the accumulated imbalance of magnetic flux which significantly decreased within 2 or 3 days prior to the major flares and tended toward zero before the onsets of the flares, suggesting a

possible relationship between a decrease of significant flux imbalance of active regions and major geomagnetic events.

Luhmann et al. (2003) also studied the influence of active regions to the configuration of the global magnetic field. They found that the topological structure of the global magnetic field is sensitive to the location, orientation, and strength of the bipolar active region involved. Specifically, when an active region with a large tilt angle emerges into the solar corona, it can cause significant topological changes in the large-scale coronal magnetic field resembling observations during some simple CMEs, suggesting a possible scenario to trigger CMEs.

We have been developing our scheme for prediction of the radial magnetic field and solar wind speed near the Earth. The solar wind speed near the Earth has been predicted on the basis of an experienced inverse relationship between the Flux Tube Expansion (FTE) factor and the solar wind speed established by Levine el al. (1977) and Wang and Sheeley (1990). The correlation between the FTE, computed using the potential field source surface (PFSS) model and the global distribution of the photospheric magnetic field, and solar wind speed is not always significant, however. We found that a possible reason to cause this discrepancy is interaction between solar wind streams with different speeds, which is usually neglected in calculations; and we also found that there is an optimum Nmax, truncation number of the spherical harmonic expansion for coronal magnetic field calculation, for the highest correlation coefficient of FTE and solar wind speed (Balachandran and Zhao, 2003).

There are two kinds of interaction between solar wind streams. One is that generated by a high speed stream flowing ahead of a low speed stream. This produces a speed profile at 1 AU that includes a rarefaction region in between the streams with speed gradually lowering from the high speed to the low speed. The other is that generated by a low speed stream flowing ahead of a high speed stream. This produces an "Interaction Region" between the streams. On the other hand, since the magnetic field in coronal holes varies smoothly from one point to another, and the magnetic field computed using the PFSS model on the source surface varies significantly, especially near boundaries of open field region or near magnetic neutral lines, the FTE computed using the PFSS model is determined mainly by the computed source surface field and the computed FTE varying from the hole's center to the hole's boundary may roughly match the speed profile including a rarefaction region if the solar wind from the hole's center is ahead of the solar wind from the hole's boundary. However, it certainly cannot match the speed profile including an Interaction Region if the solar wind from the hole's center is behind the solar wind from the hole's boundary. That is why the correlation coefficients obtained using the PFSS model sometimes can reach significantly high and sometimes cannot (Zhao and Balachandran, 2003).

The radial component of the heliospheric magnetic field measured by Ulysses is latitude-independent (Smith, 1995) and basically uniform on a spherical surface, and the nearly uniform distribution is assumed to be formed near the Sun (Suess, 1996). Thus the magnetic field on the source surface near the Alfven critical point should be nearly uniform, significantly different from the one computed using the PFSS model. By using the horizontal current-current sheet-source surface model (Zhao and Hoeksema, 1995; Zhao, Hoeksema and Rich, 2002) we have produced nearly uniform distribution of the magnetic field near the Alfven critical point located at 15 R_o, and its extension to 1 AU matches well with the solar rotation running average of in situ observations of the solar wind near the Earth orbit (Zhao et al., 2002), as shown in Figure 1. This Figure shows a comparison of in situ observations of the radial component of the interplanetary magnetic field (IMF) during the years of 1976 and 1986 with calculations. The black dots denote the daily mean of signed hour-average of the radial IMF. The ambient radial IMF, obtained by running average of the daily mean over 27 days, is denoted by the

green dots. A 5-day shift is used to map the observations neat 1 AU to the Alfven critical point. The black lines denote the radial IMF computed at the location of the Earth using the synoptic charts and the HCCSSS model at the location of the Earth. It is assumed in the computation that there is no interaction between solar wind flow and the interplanetary magnetic field beyond the Alfven critical point. Here 'Polarity match' denotes the ratio of the number of dots when the prediction of polarity is consistent with observation to the total number of dots. The first and second number on the right hand are for daily mean and its 27-day running average. 'Strength deviation' is the RMS of the difference between the predicted strength with correct polarity and the observed one.

IMPACT/APPLICATIONS

The magnetic configuration of solar active regions somehow appears to be related to solar transients. This seems to suggest a way to measure the probability for a solar eruption.

Understanding and improvement of the observed inverse relationship between the flux tube expansion factor and the solar wind speed will help reveal the type of solar wind, and may lead to a better prediction scheme for space weather.

TRANSITIONS

Observations are used to make monthly predictions of solar wind speed (N. Sheeley at NRL) using WSO and other solar data sources. Based on the updated daily global photospheric magnetic field provided by WSO and the models developed here and elsewhere, the daily prediction of solar wind speed, interplanetary magnetic field polarity, and the location of coronal holes are provided by N. Arge and V. Pizzo at the Rapid Prototyping Center at SEC in Boulder. Daily solar magnetic mean field values are also provided to the Solar Forecast Center in Boulder.

WSO observations are widely used for research by various institutes and organizations in solar physics and space physics communities, supported by agencies such as ONR, other Department of Defense, NSF, and NASA.

For example, in the past year, our NRL colleagues used WSO magnetograph data for various research programs, including studies on the fluctuation component of the Sun's large-scale magnetic field (Wang and Sheeley, 2003), coronal white-light jets (Wang and Sheeley, 2002), the role of meridional flow in determining the evolution of the Sun's large-scale field (Wang, Sheeley, and Lean, 2002), and relationship of the long-term variation of total open flux of the Sun and the sunspot activity (Wang and Sheeley, 2002).

The data are also used by many others. For example, Roussev and his colleagues at Michigan University, supported by DoD through a MURI (Multiple-disciplinary University Research Initiative) grant to the University of Michigan, presented a new compressible MHD model for simulating the three-dimensional structure of the solar wind under steady state condition, by means of using our coronal structure calculated from WSO observations, available at WSO's website. Their simulation code is very sophisticated with application of the adaptive grid technique, and for the first time the observation data is employed in this code (Roussev et al., 2003). This study demonstrates a good agreement between observation and simulation, suggesting a possibility to incorporate magnetic field observations into numerical simulation aimed at modeling the global heliosphere and space weather.
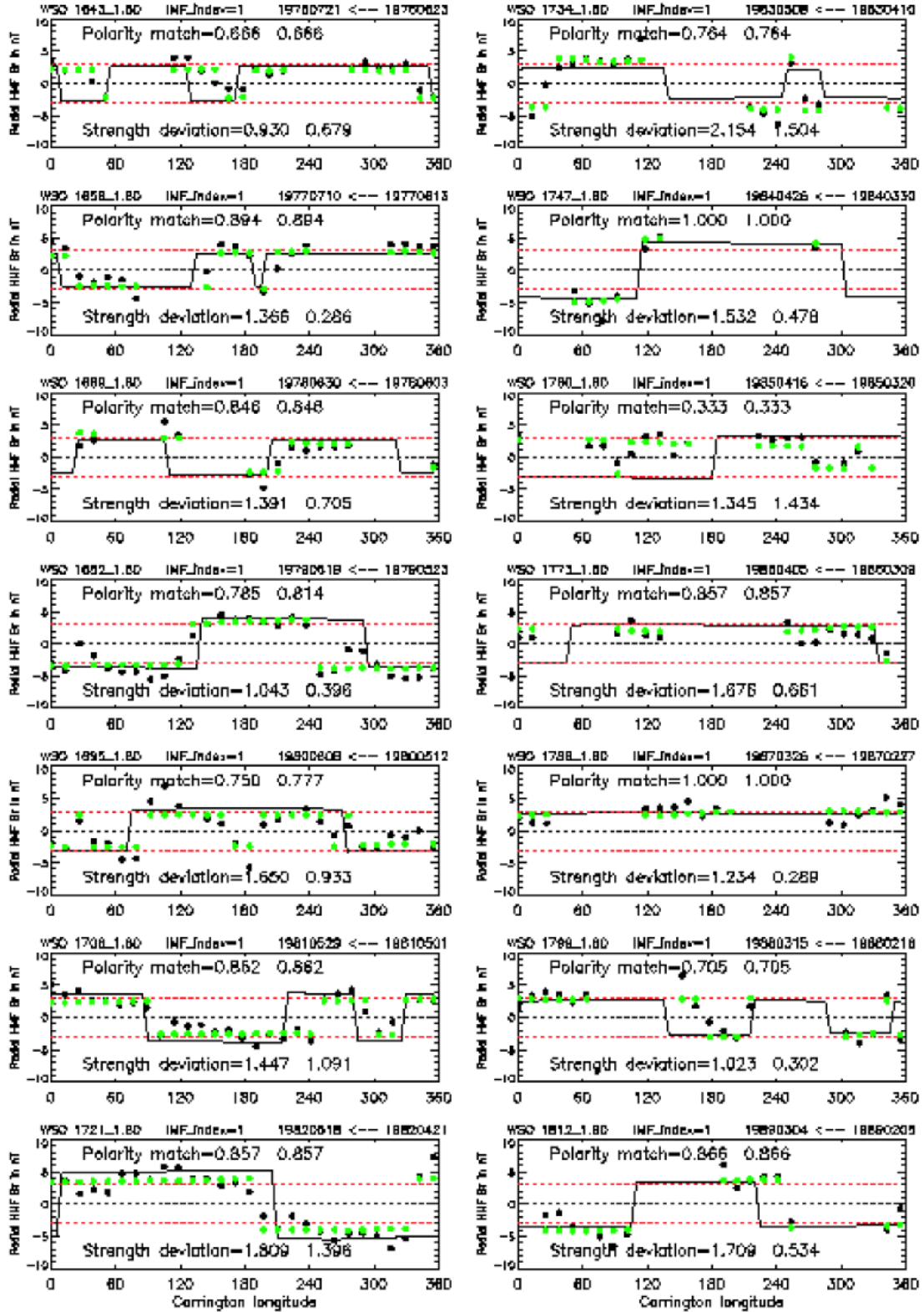
Figure 1 shows a comparison of observation and calculation for interplanetary magnetic field in a set of 14 Carrington rotation plots showing polarity of the modeled and observed field. The correlation is typically 0.75 to 0.85.

RELATED PROJECTS

Operation of the Wilcox Solar Observatory is supported in roughly equal measures by NASA, NSF and ONR.

Our group is responsible for the SOI/MDI on SOHO and progress on our scientific objectives will benefit from analysis of MDI and other SOHO data. Such direct comparisons are being supported by NASA funds.

Collaborations with other observers and modelers increase our understanding of the whole solar terrestrial system. In addition to other ONR sponsored researchers (Pizzo and Arge, Sheeley and Wang) mentioned above, we participate in space-weather-forecasting projects which are funded by the Department of Defense (DoD) through a MURI (Multiple-disciplinary University Research Initiative) grants to the University of California at Berkeley and the University of Michigan, and funded by National Science Foundation (NSF) through a CISM (the Center for Integrated Space Weather Modeling) grant to the Boston University. We also involve in the investigation of changing coronal field configurations by J. Luhmann at UC Berkeley, the development of MHD models of the coronal field by Mikic and Linker of SAIC in San Diego and S. T. Wu of UAH in Huntsville.

REFERENCES

Bala, B. and X. P. Zhao, in preparation, 2003.

Levine, R. H., Altschuler, M. D., and Harvey, J. W., *JGR*, **82**, 1061, 1977.

Roussev, I. I., Gombosi, T. I., Sokolov, I. V., et al., "A three-dimensional model of the solar wind incorporating solar magnetogram observations", *Astrophysical Journal*, **595**, L57, 2003.

Smith, E. J. and A. Balogh, *GRL*, 22, 23, 3317, 1995.

Suess, S. T., et al., *Astron. Astrophys.*, **316**, 304, 1996.

Wang, Y-M, Sheeley, N. R., Jr., "On the fluctuating component of the Sun's large-scale magnetic field", *Astrophysical Journal,* **590**, 1111, 2003.

Wang, Y-M, Sheeley, N. R., Jr., "Coronal white-light jets near sunspot maximum", *Astrophysical Journal,* **575**, 542, 2002.

Wang, Y-M, Sheeley, N. R., Jr., "Sunspot activity and the long-term variation of the Sun's open magnetic flux", *JGR,* **107**, 1302, 2002.

Wang, Y-M, Sheeley, N. R., Jr., Lean, J., "Meridional flow and the solar cycle variation of the Sun's open magnetic flux", *Astrophysical Journal,* **508**, 1188, 2002.

Wang and Sheeley, *ApJ.*, **355**, 726, 1990.

Zhao, X. P. and J. T. Hoeksema, *JGR.*, **100**, 33, 1995.

Zhao, X. P. and B. Bala, in preparation, 2003.

PUBLICATIONS

Luhmann, J. G., Y. Li, X. P. Zhao, S. Yashiro, "Coronal magnetic field context of simple CMEs inferred from global potential field models"*, Solar Physics*, **213**, 367, 2003.

Tian, Lirong and Y. Liu, "Tilt and alpha_best of major flare-producing active regions"*, A. Ap. Lett.,* **407***,* L13, 2003a*.*

Tian, Lirong and Y. Liu, "Relationship Between Decrease of Net Magnetic Flux and Solar Major Events"*, A. Ap.,* **406**, 337, 2003b.

Tian, Lirong, Y. Liu, and H. Wang, "Latitude and Magnetic Flux Dependence of Tilt Angle Of Bipolar Magnetic Regions"*, Solar Physics*, **215**, 281, 2003.

Tian, Lirong, Y. Liu, and H. Wang, "The most severe super active regions in the 22nd and 23rd cycles", *Solar Physics*, **209**, 361, 2002.

Zhao, X. P., J. T. Hoeksema, and N. B. Rich, *ASR*, 29, 3, 411, 2002.